US009149776B2

(12) **United States Patent**
Drohan

(10) **Patent No.: US 9,149,776 B2**
(45) **Date of Patent: Oct. 6, 2015**

(54) **SYSTEMS AND METHODS FOR LIQUID FUEL MODELING**

(75) Inventor: **John Benjamin Drohan**, Greer, SC (US)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 663 days.

(21) Appl. No.: **13/549,186**

(22) Filed: **Jul. 13, 2012**

(65) **Prior Publication Data**

US 2014/0018973 A1 Jan. 16, 2014

(51) **Int. Cl.**

B01F 15/00 (2006.01)
G05D 21/02 (2006.01)
F02C 9/00 (2006.01)

(52) **U.S. Cl.**

CPC *B01F 15/00123* (2013.01); *F02C 9/00* (2013.01); *G05D 21/02* (2013.01); *F05D 2270/71* (2013.01)

(58) **Field of Classification Search**

CPC G05D 23/00; F02C 9/00
USPC 700/275, 286, 287, 290, 300, 265; 701/100, 101, 104, 59, 99; 60/39.01, 60/272, 625, 602
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,283,087	B1 *	9/2001	Isaksen	123/243
7,742,904	B2	6/2010	Healy et al.	
2004/0261414	A1 *	12/2004	Araki	60/602
2009/0308608	A1 *	12/2009	Kaminsky et al.	166/272.1

OTHER PUBLICATIONS

Avallone, Eugene A., Marks' Standard Handbook for Mechanical Engineers, pp. 7-10 through 7-16, 1996.

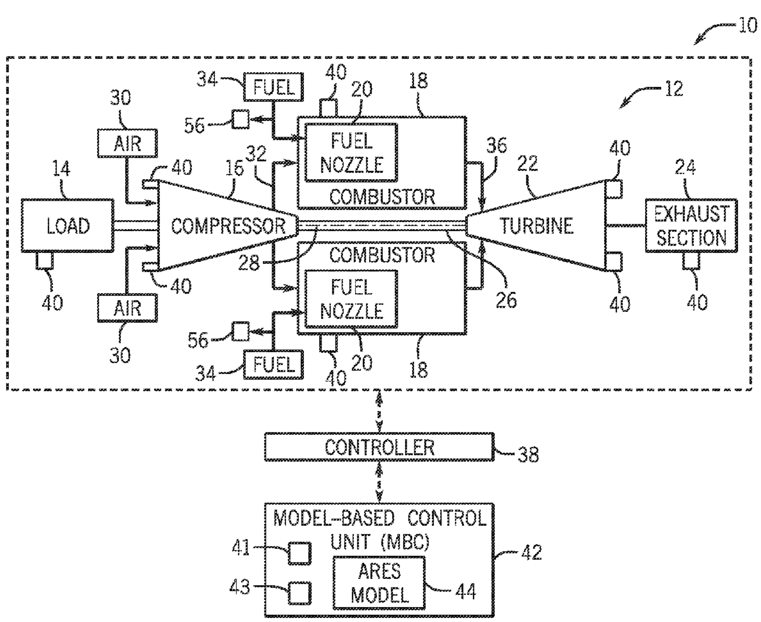
* cited by examiner

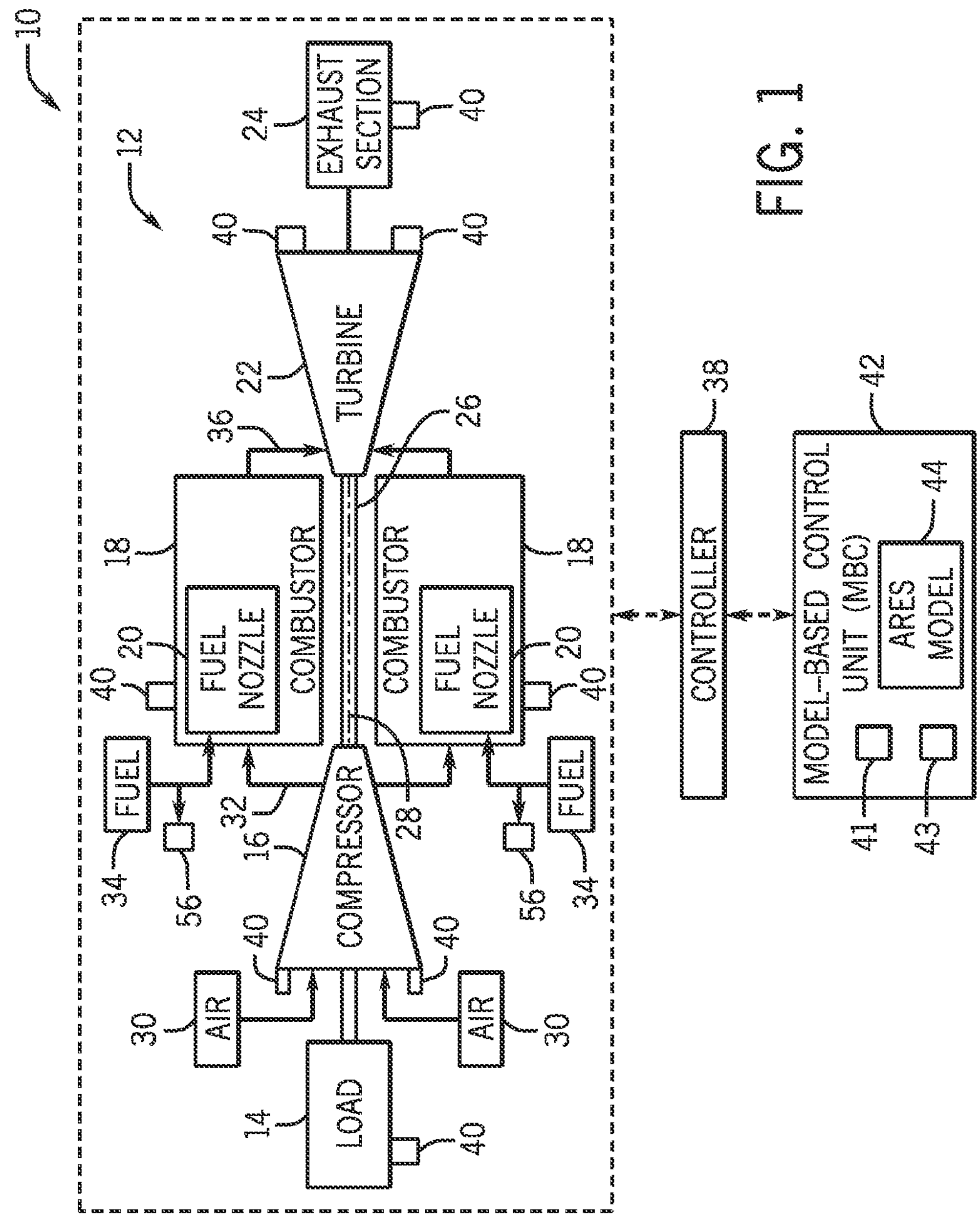
Primary Examiner — Mohammad Ali
Assistant Examiner — Ziaul Karim
(74) *Attorney, Agent, or Firm* — Fletcher Yoder, P.C.

(57) **ABSTRACT**

A system includes a model-based control unit configured to receive a lower heating value for a liquid fuel having a composition. The processor is configured to determine a specific gravity, a hydrocarbon ratio, or both, for the liquid fuel based, at least in part, on the lower heating value of the liquid fuel. The processor is configured to compare the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel to a collection of hydrocarbon ratios, specific gravities, and/or lower heating values for a plurality of mixtures of methane and ethylene. The processor is configured to identify a mixture of methane and ethylene from the collection that best matches the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel and configured to use the identified mixture of methane and ethylene as a model for the composition of the liquid fuel.

9 Claims, 3 Drawing Sheets

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EXHAUST SECTION
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CONTROLLER
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MODEL-BASED CONTROL UNIT (MBC)
42
ARES MODEL
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43

FIG. 1

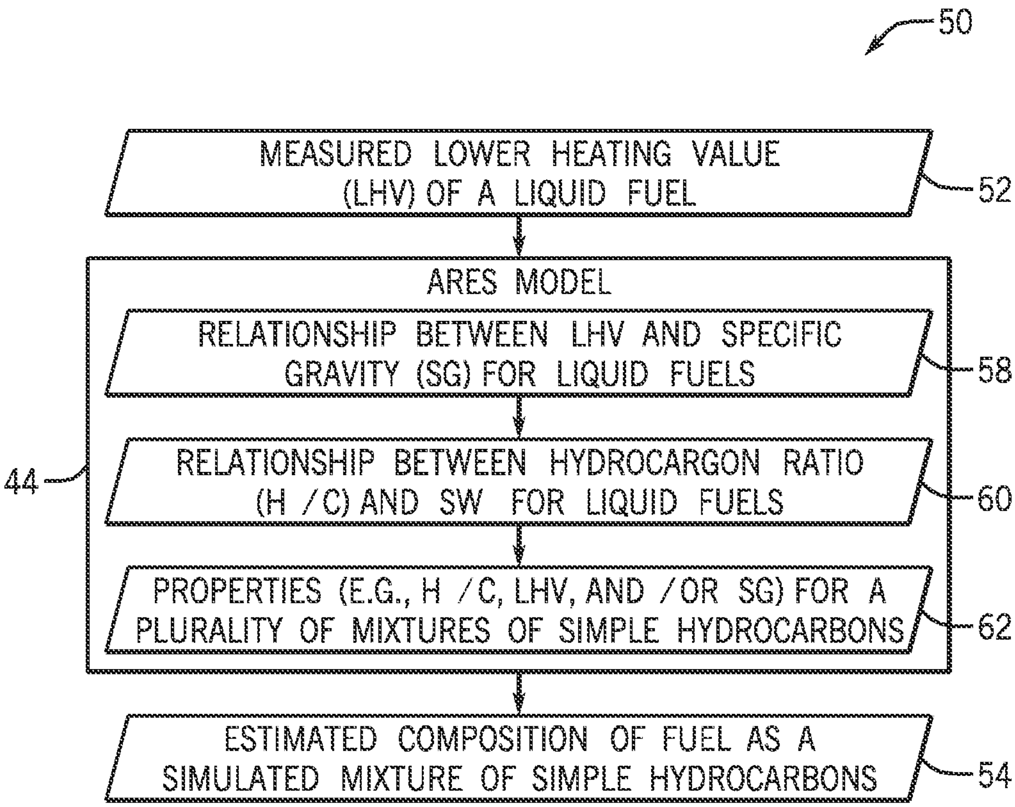
50
MEASURED LOWER HEATING VALUE (LHV) OF A LIQUID FUEL
52
ARES MODEL
RELATIONSHIP BETWEEN LHV AND SPECIFIC GRAVITY (SG) FOR LIQUID FUELS
58
RELATIONSHIP BETWEEN HYDROCARGON RATIO (H /C) AND SW FOR LIQUID FUELS
60
44
PROPERTIES (E.G., H /C, LHV, AND /OR SG) FOR A PLURALITY OF MIXTURES OF SIMPLE HYDROCARBONS
62
ESTIMATED COMPOSITION OF FUEL AS A SIMULATED MIXTURE OF SIMPLE HYDROCARBONS
54

FIG. 2

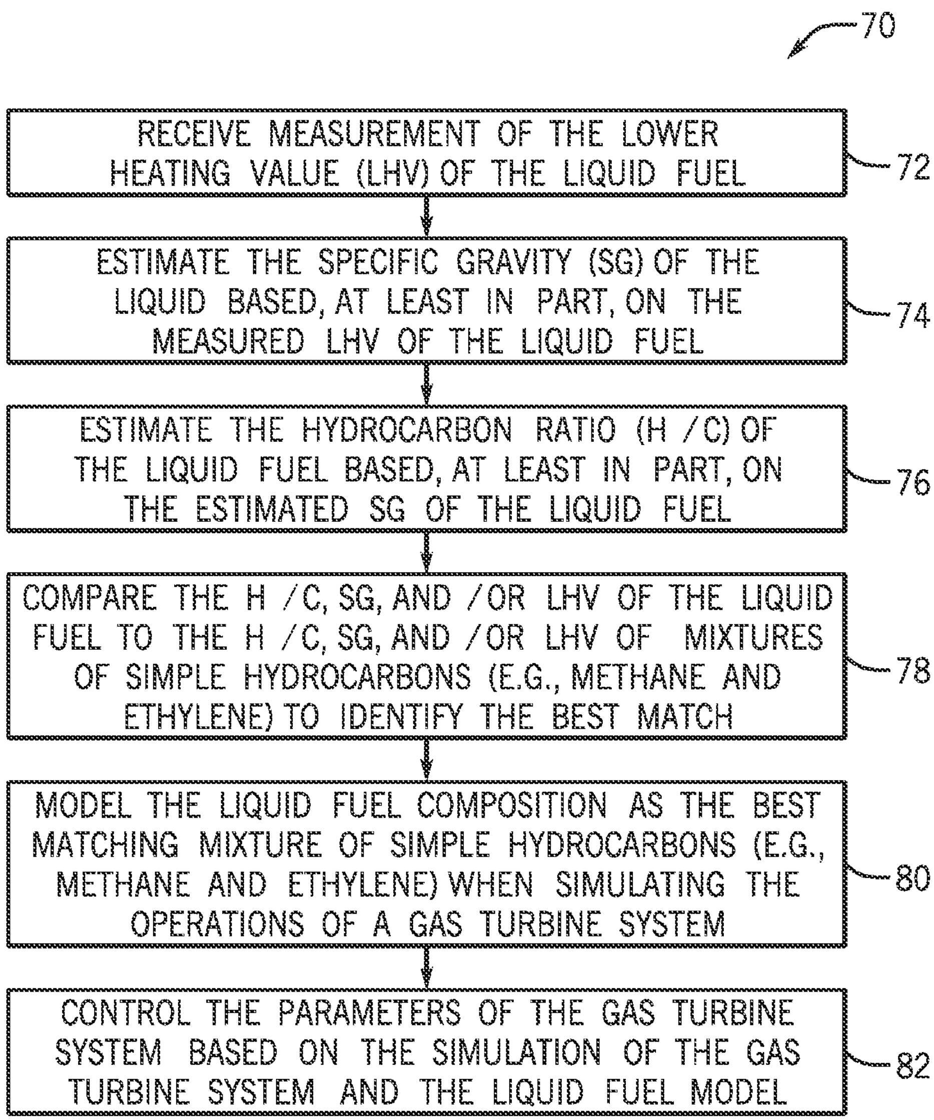
70
RECEIVE MEASUREMENT OF THE LOWER HEATING VALUE (LHV) OF THE LIQUID FUEL
72
ESTIMATE THE SPECIFIC GRAVITY (SG) OF THE LIQUID BASED, AT LEAST IN PART, ON THE MEASURED LHV OF THE LIQUID FUEL
74
ESTIMATE THE HYDROCARBON RATIO (H /C) OF THE LIQUID FUEL BASED, AT LEAST IN PART, ON THE ESTIMATED SG OF THE LIQUID FUEL
76
COMPARE THE H /C, SG, AND /OR LHV OF THE LIQUID FUEL TO THE H /C, SG, AND /OR LHV OF MIXTURES OF SIMPLE HYDROCARBONS (E.G., METHANE AND ETHYLENE) TO IDENTIFY THE BEST MATCH
78
MODEL THE LIQUID FUEL COMPOSITION AS THE BEST MATCHING MIXTURE OF SIMPLE HYDROCARBONS (E.G., METHANE AND ETHYLENE) WHEN SIMULATING THE OPERATIONS OF A GAS TURBINE SYSTEM
80
CONTROL THE PARAMETERS OF THE GAS TURBINE SYSTEM BASED ON THE SIMULATION OF THE GAS TURBINE SYSTEM AND THE LIQUID FUEL MODEL
82

FIG. 3

SYSTEMS AND METHODS FOR LIQUID FUEL MODELING

BACKGROUND OF THE INVENTION

The subject matter disclosed herein relates to gas turbine systems and, more specifically, to gas turbines that use liquid fuel.

In general, gas turbine systems may consume a fuel to produce rotational energy to power a load. Certain gas turbine systems are capable of combusting a liquid fuel (e.g., an oil or slurry) in one or more combustors in order to drive a turbine. In such systems, there may be significant variation in the chemical composition of the liquid fuel over time. As the fuel composition fluctuates, this may cause undesirable inconsistency in the operation of the gas turbine system.

BRIEF DESCRIPTION OF THE INVENTION

Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

In an embodiment, a system includes a model-based control unit configured to receive a lower heating value for a liquid fuel having a composition. The processor is configured to determine a specific gravity, a hydrocarbon ratio, or both, for the liquid fuel based, at least in part, on the lower heating value of the liquid fuel. The processor is configured to compare the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel to a collection of hydrocarbon ratios, specific gravities, and/or lower heating values for a plurality of mixtures of methane and ethylene. The processor is configured to identify a mixture of methane and ethylene from the collection that best matches the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel and configured to use the identified mixture of methane and ethylene as a model for the composition of the liquid fuel.

In another embodiment, a method includes determining an estimated specific gravity of a liquid fuel based, at least in part, on a measured lower heating value of a liquid fuel having a composition. The method includes determining an estimated hydrocarbon ratio of the liquid fuel based, at least in part, on the estimated specific gravity of the liquid fuel. The method includes selecting a hydrocarbon mixture from a plurality of hydrocarbon mixtures to serve as a model for the composition of the liquid fuel. Further, the selected hydrocarbon mixture has a hydrocarbon ratio, a specific gravity, and/or a lower heating value similar to the estimated hydrocarbon ratio, the estimated specific gravity, and/or the measured lower heating value of the liquid fuel.

In another embodiment, a non-transitory, computer-readable medium stores instructions executable by a processor of an electronic device, the instructions comprising instructions to determine a first lower heating value of a liquid fuel, wherein the liquid fuel comprises a composition, a first hydrocarbon ratio, and a first specific gravity. The instruction include instructions to identify a mixture of methane and ethylene having a second hydrocarbon ratio, second specific gravity, and/or second lower heating value that is similar to the first hydrocarbon ratio, the first specific gravity, and/or the first lower heating value to serve as a model of the composition of the liquid fuel when simulating a combustion system consuming the liquid fuel during operation. The instructions include instructions to modify a parameter of the combustion system based, at least in part, on the simulation of the combustion system.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. **1** is a block diagram of a turbine system having a model-based control (MBC) unit utilizing an Adaptive Real-time Engine Simulator (ARES) model, in accordance aspects of the present technique;

FIG. **2** is a hybrid flow diagram illustrating the flow of information into and out of the ARES model, in accordance with aspects of the present technique; and

FIG. **3** is a flow diagram illustrating a process by which the MBC may model the composition of a liquid fuel and use the model to simulate and control the operations of a gas turbine system, in accordance with aspects of the present technique.

DETAILED DESCRIPTION OF THE INVENTION

One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

As mentioned, certain gas turbine systems are capable of consuming a liquid fuel (e.g., an oil or slurry) during operation. However, since there may be significant variation in the chemical composition of the liquid fuel over time, the parameters of the gas turbine system (e.g., the rotational speed of the turbine, flame temperature, combustion dynamics, energy output, exhaust temperature, exhaust composition, exhaust volume, and the like) may also vary. This may produce undesirable inconsistency in the operation of the gas turbine system. Furthermore, in certain situations, the exact composition of a liquid fuel may not be known. As such, it may be desirable for a gas turbine system to have a system for modeling the chemical composition of the liquid fuel.

Accordingly, the presently disclosed system enables the creation of a model for the chemical composition of a liquid fuel based on a simulated mixture of two or more simple hydrocarbons (e.g., methane and ethylene). In contrast to other methods of fuel modeling, the presently disclosed model enables an estimate of the chemical composition of the liquid fuel that is based on a determined lower heating value (LHV), also known as the net calorific value or lower calorific value (e.g., measured via calorimetry). Using this measured LHV, the presently disclosed system may determine or estimate the specific gravity (SG) and the hydrocarbon ratio (H/C) for the liquid fuel, enabling the identification of a certain mixture of simple hydrocarbons (e.g., methane and ethylene) having substantially similar properties (e.g., H/C, SG, and/or LHV) as the liquid fuel. Subsequently, the identified mixture of simple hydrocarbons may further be used by the system as a model for the liquid fuel as the system simulates a gas turbine combusting mixture during operation. Furthermore, based on the operation of the simulated gas turbine, the presently disclosed system may determine one or more parameters (e.g., fuel flow rates, air flow rates, etc.) of an actual gas turbine system to alter in order to adjust the operation of the gas turbine system.

With the forgoing in mind, FIG. **1** is a block diagram of an embodiment of a turbine system **10** that may use the presently disclosed fuel modeling techniques. While the advantages of the present fuel modeling techniques may be presented in the context of turbine system **10**, it should be appreciated that the present technique may be applicable to modeling any system that consumes or combusts a liquid fuel (e.g., a combustion system, a reactor, a furnace, or other suitable system). The illustrated turbine system **10** includes a gas turbine engine **12** coupled to a load **14**, such as an electrical generator. The gas turbine engine **12** includes a compressor **16**, a plurality of combustors **18** each having at least one fuel nozzle **20**, a turbine **22**, and an exhaust section **24**. As illustrated, one or more shafts **26** connect the load **14**, compressor **16**, and turbine **22**. The compressor **16** and the turbine **22** each include a rotor with blades, which rotate within a stator or shroud. In operation, the compressor **16** receives air **30** and delivers compressed air **32** to the combustors **18** and/or fuel nozzles **20**, which then inject fuel **34** (or an air-fuel mixture) into a combustion region in the combustors **18**. In turn, the air-fuel mixture combusts in the combustors **18** to produce hot combustion gases **36**, which drive blades within the turbine **18**. As the turbine is driven to rotate the shaft **26**, the compressor **16** is driven to compress the air **16** into the combustors **18** and/or fuel nozzles **20**.

Additionally, the illustrated turbine system **10** includes a controller **38** that may generally control the operations of the turbine system **10**. For example, in certain embodiments, the controller **38** may be coupled to a number of sensors **40** (e.g., temperature sensors, pressure sensors, clearance sensors, flow rate sensors, vibration sensors, flame sensors, or other suitable sensors) disposed throughout the gas turbine engine **12**. The controller **38** may communicate (e.g., via a network or bus) with the sensors **40** to receive information regarding the turbine engine **12**. For example, the controller **38** may communicate with a temperature sensor **40** coupled to the exhaust section **24** of the gas turbine engine **12** to receive a temperature of the exhaust gases. By further example, a flow sensor **40** coupled to the fuel nozzle **20** of the gas turbine engine **12** may communicate to the controller **38** the rate at which a liquid fuel in being supplied to the fuel nozzle **20**. Furthermore, in certain embodiments, the controller **38** may also communicate with certain components of the turbine system (e.g., the compressor **16**, the combustor **18**, the turbine **22**, intake vanes, valves, pumps, actuators, or other suitable components) to control or alter the operation of the gas turbine engine **12**. For example, the controller **38** may communicate with the compressor **16** of the gas turbine engine **12** to instruct the field device to open or close an air intake to allow more or less air **30** into the compressor **16**.

Furthermore, the illustrated turbine system **10** includes a model-based control (MBC) unit **42**. The MBC unit **42** may include non-transitory code or instructions stored in a machine-readable medium (e.g., memory **41**) and used by a processor (e.g., processor **43**) to implement the techniques disclosed herein. In general, the MBC unit **42** may utilize one or more models (e.g., the Adaptive Real-time Engine Simulator (ARES) model **44**, which may be stored in memory **41**) to simulate of the operation of a system (e.g., the turbine system **10**). Additionally, the disclosed MBC unit **42** may include one or more features of the gas turbine simulation and control systems disclosed in U.S. Pat. No. 7,742,904, entitled, "METHOD AND SYSTEM FOR GAS TURBINE ENGINE SIMULATION USING ADAPTIVE KALMAN FILTER," which is incorporated by reference herein in its entirety for all purposes. Based on the output of the models (e.g., the ARES model **44**), the MBC unit **42** may determine a number of parameters of the gas turbine engine **12** that should be altered (e.g., to improve or modify the performance of the turbine system **10**). In certain embodiments, the MBC unit **42** may be communicatively coupled to the controller **38** to receive information regarding the operation of the turbine system **10** (e.g., via sensors **40**). For such embodiments, the MBC unit **42** may additionally provide the controller **38** with instructions regarding one or more parameters of the gas turbine engine **12** that should be altered, based on the output of the model (e.g., the ARES model **44**), to modify the operation of the gas turbine system **10**. In other embodiments, the MBC unit **42** may be part of the controller **38** (e.g., as hardware, software, or a combination thereof) or may serve as the controller **38**, allowing the MBC unit **42** to directly communicate with the sensors **40** and/or the components (e.g., the compressor **16**, combustors **18**, turbine **22**, or other suitable components) of the turbine system **10** to receive information and to control the operation of the turbine system **10**.

For the turbine system **10** illustrated in FIG. **1**, the ARES model **44** may simulate the operation of a model turbine system (e.g., modeled after the turbine system **10**). For example, the ARES model **44** may receive inputs regarding the operation of the gas turbine engine **12**, either directly from the sensors **40** (e.g., via a network) or indirectly from another source (e.g., via the controller **38** or supplied by an operator). By specific example, the ARES model **44** may receive inputs from sensors **40**, including a temperature for the exhaust section **24**, a flow rate for the fuel **34** entering the fuel nozzle **20** of the combustor **18**, a flow rate for the air **30** entering the compressor **16**, the ambient conditions near the turbine system **10**, rotational speed of the turbine **22**, clearance between turbine and/or compressor blades and the surrounding shroud, exhaust emissions, vibration, combustion dynamics, and so forth. Furthermore, in certain embodiments, the ARES model **44** may receive inputs regarding the turbine system **10** from an operator or user. For example, in certain embodiments, an operator may provide the MBC unit **42** with other inputs regarding the turbine system **10**, such as information that may not be gleaned by the sensors **40**.

FIG. **2** is a hybrid flow diagram **50** illustrating the flow of information into and out of the ARES model **44**, in accordance with an embodiment of the present technique. As illustrated in FIG. **2**, the ARES model **44** receives as input a measured LHV **52** of the liquid fuel (e.g., fuel **34**) in order to output an estimated composition **54** of the liquid fuel as a simulated mixture of simple hydrocarbons. For example, in certain embodiments, a portion of the liquid fuel **34** may be sampled and analyzed by an operator using a calorimeter to determine the LHV **52** of the liquid fuel. Subsequently, the operator may provide the MBC unit **42** and/or the ARES model **44** with the measured LHV **52** via a user interface of a computer, such as a human machine interface (HMI), communicatively coupled to the MBC unit **42** and/or the ARES model **44**. In other embodiments, the turbine system **10** may be equipped with an automated device (e.g., automated calorimetry device **56** of FIG. **1**) that may automatically sample and measure the LHV **52** of the liquid fuel **34** being supplied to the combustor **18** of the turbine system **10**.

Once the measured LHV **52** of the liquid fuel has been received by the ARES model **44**, the ARES model **44** may utilize equations, tables, graphs, or other suitable data stored in the memory **43** of the MBC unit **42**, to model or estimate the composition **54** of the liquid fuel **34** from the measured LHV **52**. For example, in certain embodiments, the ARES model **44** may store and use a relationship **58** between LHV and SG for liquid fuels to determine the SG of the liquid fuel **34** from the measured LHV **52** of the liquid fuel **34**. In certain embodiments, this relationship **58** between LHV and SG for liquid fuels may be represented by the following equation:

Eq. 1

$$LHV=22{,}320-3780(SG)^2-90.8(26-15(SG))$$

As such, in certain embodiments, the ARES model **44** may use Eq. 1 (e.g., solved for SG) to calculate the SG of the liquid fuel **34** from the measured LHV **52**. In other embodiments, the ARES model **44** may include a table (e.g., a lookup table, chart, graph) of values in which each row may include a pair of LHV and a SG values (e.g., based on the relationship **58** expressed by Eq. 1). In other embodiments, the ARES model **44** may include a graph expressing the relationship **58** demonstrated by Eq. 1, in which the coordinates for each point represent a pair of corresponding LHV and SG values. Accordingly, the ARES model **44** may use an equation, table, graph, or other suitable representation of the relationship **56** between LHV and SG expressed by Eq. 1 to determine or estimate the SG of the liquid fuel **34** from the measured LHV **52**.

The ARES model **44** may further include a relationship **60** between the hydrocarbon ratio (H/C) of liquid fuels and the determined or estimated SG for the liquid fuel. This relationship **60** between H/C of liquid fuels and SG may be represented by the following equation:

Eq. 2

$$\text{Hydrocarbon ratio (H/C)}=(26-15(SG))\,(100-(26-15(SG)))^{-1}\,(12.01/1.01)$$

As with the relationship **58** between the LHV and the SG for liquid fuels, the relationship **60** between the H/C and the SG for liquid fuels may be directly calculated using the equation Eq. 2. In certain embodiments, the ARES model **44** may store the relationship **60** as a table (e.g., each row representing a pair of H/C and SG values), a graph (e.g., the coordinates of each data point representing a pair of H/C and SG values), or any other suitable representation (e.g., based on Eq. 2). Accordingly, the ARES model **44** may use one or more of these representations to determine or estimate the H/C of the liquid fuel **34** from the determined or estimated H/C.

The ARES model **44** may further include a collection of properties **62** for a plurality of simple hydrocarbon mixtures. In certain embodiments, the ARES model **44** may include a table storing the collection of properties **62** for a plurality of simple hydrocarbon mixtures. For example, the ARES model **44** include a table storing the collection of properties **62** in which each row may include a relative composition of methane and ethylene as well as the H/C, SG, and/or LHV for a particular methane and ethylene mixture. For example, in certain embodiments, the ARES model **44** may store H/C, SG, and/or LHV for a plurality of mixtures of methane (CH_4) and ethylene (C_2H_2) (e.g., ranging from approximately 1% CH_4/99% C_2H_2 to approximately 99% CH_4/1% C_2H_2). In various embodiments, simple hydrocarbon mixtures may include mixtures of methane, ethylene, acetylene, ethane, propane, propylene, or any combination thereof As discussed below, the ARES model **44** may use this collection of properties **62** for the plurality of simple hydrocarbon mixtures to identify a particular mixture (e.g., a best matching mixture) having a substantially similar H/C, SG, and/or LHV as the liquid fuel **34**.

FIG. **3** is a flow diagram illustrating an embodiment of a process **70** by which the MBC unit **42** may model the composition of a liquid fuel **34** and, further, use the model to simulate and control the operations of a gas turbine system. The process **70** may include non-transitory code or instructions stored in a machine-readable medium (e.g., memory **41** of MBC unit **42**) and used by a processor (e.g., processor **43** of MBC unit **42**) to estimate or model the composition of the liquid fuel. The illustrated process **70** begins with the MBC unit **42** receiving (block **72**) a measurement for the LHV of the liquid fuel. As mentioned, in certain embodiments, the LHV **52** of the liquid fuel may be measured via calorimetry, either manually (e.g., through the actions of the operator using a calorimeter to analyze a sample of the liquid fuel **34**) or automatically (e.g., via the automated calorimeter **56** that is communicatively coupled to the MBC unit **42**). As discussed below, once the MBC unit **42** has received the LHV **52** of the liquid fuel, the MBC unit **42** may utilize the ARES model **44**, including the aforementioned stored relationships and properties **58**, **60**, and **62**, to generate an estimated composition **54** of the liquid fuel.

Accordingly, after receiving the measured LHV **52** of the liquid fuel, the ARES model **44** may utilize the relationship **58** between LHV and SG for liquid fuels to determine or estimate (block **74**) the SG of the liquid fuel based, at least in part, on the measured LHV **52** of the liquid fuel. For example, in certain embodiments, the relationship **58** between LHV and SG for liquid fuels may be stored in a table, and the ARES model **44** may determine the LHV value in the table that is the closest match to the measured LHV **52** in order to determine or estimate the corresponding SG of the liquid fuel **34**. Similarly, once the ARES model **44** has determined or estimated the SG of the liquid fuel (block **74**), the ARES model **44** may also determine or estimate (block **76**) the H/C of the liquid fuel based, at least in part, on the determined or estimated SG of the liquid fuel. For example, in certain embodiments, the relationship **60** between SG and H/C for liquid fuels may be stored in a table, and the ARES model **44** may determine the SG value in the table that is the closest match to the determined or estimated SG in order to determine or estimate the corresponding H/C of the liquid fuel **34**.

Then, the ARES model **44** may compare the estimated and/or measured properties of the liquid fuel **34** (e.g., the measured LHV **52**, the estimated SG from block **74**, and/or the estimated H/C from block **76**) to the collection **62** of properties for a plurality of mixtures of simple hydrocarbons (e.g., methane and ethylene) to identify the best match. It should be appreciated that the mixtures of simple hydrocarbons may include mixtures having two, three, four, five, six, seven, eight, nine, ten, or more simple hydrocarbons species, in which each of the simple hydrocarbon species may include between 1 and 16 carbon atoms. For example, in certain embodiments, the collection of properties **62** may be in the form of a table storing properties (e.g., composition, LHV, SG, and/or H/C) for a number of mixtures of methane and ethylene. Accordingly, in certain embodiments, the ARES model **44** may use the determined or estimated H/C (e.g., from block **76**) alone to identify a mixture of methane and ethylene from the table having the best matching (e.g., closest) H/C value. For example, the ARES model **44** may determine that the best estimate for the composition of the liquid fuel is a specific mixture of methane and ethylene (e.g., 5% CH_4 and 95% C_2H_2, 50% CH_4 and 50% C_2H_2, or 25% CH_4 and 75% C_2H_2) identified through the comparison of the H/C value determined for the liquid fuel in block **76** and the H/C values stored in the collection of properties **62** for the various methane and ethylene mixtures. In other embodiments, the ARES model **44** may attempt to identify a mixture of methane and ethylene from the table having similar H/C and SG values or similar H/C, SG, and LHV values. In certain embodiments, if two or more simple hydrocarbon mixtures included in the collection **62** are equally good matches for the H/C value of the liquid fuel **34**, then the ARES model **44** may utilize another property of the liquid fuel (e.g., SG and/or LHV) to determine the better matching simple hydrocarbon mixture to model the liquid fuel **34**.

Based on the comparison in block **78**, the MBC unit **42** may model (block **80**) the fuel composition of the liquid fuel as the best matching mixture of simple hydrocarbons when simulating the operations of the turbine system **10**. That is, as the MBC unit **42** simulates the operations of the turbine system **10**, the MBC unit **42** may estimate a number of parameters of the turbine system **10** using the best matching mixture of simple hydrocarbons identified in block **78** as a model or approximation for the composition liquid fuel **34**. For example, the MBC unit **42** may simulate the flow rate of the liquid fuel **34**, the air flow rate **34** of the air being mixed with the liquid fuel **34**, the power output of the gas turbine engine **12** consuming the liquid fuel **34**, the temperature of the exhaust section **24**, the composition of the combustion byproducts in the exhaust section **24**, as well as any other thermodynamic and/or performance related parameters of the turbine system **10**.

Furthermore, in certain embodiments, the MPC unit **42** may additionally control (block **82**) the parameters of the turbine system **10** based on the model of the turbine system and the liquid fuel. In certain embodiments, the MBC unit **42** may be communicatively coupled to the various components of the turbine system **10** and may alter one or more parameters of the turbine system **10** by providing instructions to the components (e.g., the compressor **16**, the combustor **18**, the turbine **22**, valves, pumps, actuators, and so forth) of the turbine system **10**. For example, based on the model for the liquid fuel composition determined in block **80**, the MBC unit **42** may determine that the flow rate of the fuel entering the fuel nozzle **20** should be adjusted, and may send instructions to the fuel nozzle **20** and/or combustor **18** accordingly. By further example, based on the model for the liquid fuel composition, the MBC unit **42** may also determine that the air flow rate into the compressor **16** is too high, and may send instructions to the compressor **16** to reduce the flow rate of air **30** at the intake, or vice versa.

Technical effects of the presently disclosed technique include enabling the modeling of the composition of liquid fuels of unknown composition using a measured lower heating value (LHV). Using the disclosed ARES model **44**, the presently disclosed model-based control unit **42** may simulate the operations of the turbine system consuming the liquid fuel. In particular, the disclosed ARES model **44** may enable an approximation of the properties (e.g., LHV, SG, and/or H/C) of the liquid fuel using a mixture of simple hydrocarbons (e.g., methane and ethylene). The disclosed model-based control (MBC) unit **42** may further utilize this model for the liquid fuel to determine how to modify the parameters of the turbine system **10** during operation. For example, since liquid fuel of a turbine system **10** may vary in composition over time, the disclosed MBC unit **42** may model (e.g., in real-time or near real-time) the composition of the liquid fuel being consumed by a gas turbine system (e.g., based upon the measured LHV value), and adjust one or more parameters of the gas turbine accordingly to avoid or reduce any undesirable inconsistency in the operation of the gas turbine system.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

The invention claimed is:

1. A system, comprising:

a gas turbine system configured to consume a liquid fuel having a composition, wherein the gas turbine system comprises:

a calorimeter configured to measure and provide a lower heating value of the liquid fuel;

a model-based control unit communicatively coupled to the calorimeter and configured to control the gas turbine system, wherein the model-based control unit comprises a memory coupled to a processor, wherein the processor is configured to:

receive the lower heating value for the liquid fuel from the calorimeter;

determine a specific gravity, a hydrocarbon ratio, or both, for the liquid fuel based, at least in part, on the lower heating value of the liquid fuel;

compare the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel to a collection of hydrocarbon ratios, specific gravities, and/or lower heating values for a plurality of mixtures of methane and ethylene;

identify a mixture of methane and ethylene from the collection of hydrocarbon ratios, wherein a hydrocarbon ratio, a specific gravity, and/or a lower heating value of the identified mixture is equal to the hydrocarbon ratio, the specific gravity, and/or the lower heating value of the liquid fuel;

model one or more parameters of the gas turbine system during operation using the identified mixture of methane and ethylene as a model for the composition of the liquid fuel; and

control the one or more parameters of the gas turbine system based, at least in part, on the model for the composition of the liquid fuel.

2. The system of claim **1**, wherein the one or more parameters of the gas turbine system comprise exhaust temperature, exhaust composition, combustor temperature, fuel flow rates, air flow rates, or a combination thereof.

3. The system of claim **1**, wherein the collection comprises one or more tables of hydrocarbon ratios, specific gravities, and/or lower heating values for the plurality of mixtures of methane and ethylene.

4. The system of claim **1**, wherein the collection comprises one or more graphs of hydrocarbon ratios, specific gravities, and/or lower heating values for the plurality of mixtures of methane and ethylene.

5. A method of controlling, using a model-based control unit, a gas turbine system that consumes a liquid fuel having a composition, comprising:

receiving, at a processor of the model-based control unit that is coupled to a memory of the model-based control unit, a measured lower heating value for the liquid fuel from a calorimeter that is communicatively coupled to the model-based control unit;

determining, using the processor of the model-based control unit, an estimated specific gravity, an estimated hydrocarbon ratio, or both, for the liquid fuel based, at least in part, on the measured lower heating value of the liquid fuel;

identifying, using the processor of the model-based control unit, mixture of methane and ethylene from a plurality of hydrocarbon mixtures, wherein a hydrocarbon ratio, a specific gravity, and/or a lower heating value of the identified mixture of methane and ethylene is equal to the estimated hydrocarbon ratio, the estimated specific gravity, and/or the measured lower heating value of the liquid fuel;

modeling, using the processor of the model-based control unit, one or more parameters of the gas turbine system during operation using the identified mixture of methane and ethylene as a model for the composition of the liquid fuel; and

controlling, using the processor of the model-based control unit, the one or more parameters of the gas turbine system based, at least in part, on the model for the composition of the liquid fuel.

6. The method of claim **5**, wherein the one or more parameters of the gas turbine system comprise exhaust temperature, exhaust composition, power output, fuel flow rates, air flow rates, or a combination thereof.

7. The method of claim **5**, comprising determining the measured lower heating value of the liquid fuel using the calorimeter and sending the measured lower heating value to the processor of the model-based control unit.

8. The method of claim **5**, wherein the estimated specific gravity of the liquid fuel is determined using a graph, an equation, or a table that correlates specific gravities and lower heating values of liquid fuels.

9. The method of claim **5**, wherein the estimated hydrocarbon ratio of the liquid fuel is determined using a graph, an equation, or a table that correlates hydrocarbon ratios and specific gravities of liquid fuels.

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